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COMPARISON BETWEEN 1-MINUTE AND 15-MINUTE AVERAGES  
OF TURBULENCE PARAMETERS

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ABSTRACT

Sonic anemometers are good instruments for measuring temperature and wind speed fast enough to calculate the temperature and wind structure parameters used to calculate the variance in the acoustic index of refraction. However, the turbulence parameters are typically 15-minute averaged point measurements. There are several problems associated with making point measurements and using them to represent a turbulence field. This paper will examine some of the sonic anemometer data analyzed from the Joint Acoustic Propagation Experiment (JAPE) conducted during July 1991 at DIRT Site located at White Sands Missile Range, New Mexico.

INTRODUCTION

A sonic anemometer is an instrument used to measure the u, v, and w components of the wind field and temperature with time. A sonic anemometer consists of a pair of acoustic transmitters and receivers, spaced from 10 to 25 cm apart, that send and receive acoustic pulses at the rate of several hundred times per second. The pulses are averaged to give a data rate of 10 Hz. Sonics provide the wind component and temperature data required for computing fluxes of heat, momentum, and moisture which define the state of the surface layer by the eddy correlation method.

Sonics operate on the principle that the travel time between transmitter and receiver is a function of the speed of sound plus the component of the wind speed in the direction of propagation. A sample is composed of two pulses: one pulse traveling in one direction and another pulse traveling in the opposite direction. If the two measured speed of sound

samples are subtracted, the difference will be twice the component of the wind speed along the axis of the transmitter-receiver since the temperature is independent of the direction of propagation. Two pairs of transmitter-receivers will provide the horizontal wind field and three pairs will provide the three-dimensional wind field. The sum of the two measurements will be proportional to the temperature since the wind speed component will be subtracted out. Figures 1 and 2 show an example of the output from a sonic anemometer.

There were five sonic anemometers used in this analysis located on a 100 ft walk-up tower at intervals of 2, 4, 8, 16, and 32 meters. They were located approximately 2 meters from the tower along an East-West axis. The graphs of the data use a notation of Sonic 1, 2, 3, 4, and 5 which corresponds to the heights given previously. As a check to see if the wind was blowing through the tower, a band of arrows is placed on the graph showing wind speed and direction. The band of arrows indicates the solid angle of the tower as "seen" by the sonic anemometers. All times shown, unless otherwise stated, are Greenwich Mean Time.

### CALCULATING TURBULENCE PARAMETERS

From turbulence theory, the structure parameter  $C_x^2$  in a locally isotropic field is defined by<sup>1</sup>

$$C_x^2 = \frac{\langle [\chi(\vec{r}_1) - \chi(\vec{r}_2)]^2 \rangle}{|\vec{r}|^{2/3}} \quad (1)$$

where  $|\vec{r}|$  is the spatial separation distance,  $\chi(\vec{r})$  is the measured quantity at each point, and the angle brackets indicate performing an ensemble average. A sonic anemometer makes a measurement at a single point instead of at two points separated by a distance  $r$ . The above equation can be rewritten into a form usable for a single point sensor. Taylor's frozen turbulence hypothesis<sup>2</sup> states that the spatial separation of the turbulence can be calculated from the temporal separation ( $\Delta t$ ) times the mean wind speed. This allows Eq. (1) to be written as

$$C_x^2 = \frac{[\overline{\chi(t_1) - \chi(t_2)}]^2}{(u \Delta t)^{2/3}} \quad (2)$$

where  $\chi(t)$  is the fluctuating quantity sampled at two instances with a temporal separation  $\Delta t$ , the overbar indicates a time average, and  $u$  is the mean wind speed. This equation allows

for the temperature and wind structure parameters to be calculated from the sonic anemometer data.

## EXAMINATION OF RESULTS

The best place to begin is looking at a set of good turbulence data. Figure 3 shows a comparison between 1-minute and 15-minute averages of the wind structure parameter with time. The dashed line is the wind speed with time. The 1-minute averages show some variability about the 15-minute averages in the wind structure parameter. Forty minutes into the comparison, there is an increase in the wind structure parameter which translates into an increase in the mechanical turbulence. Figure 4 shows the wind speed and direction with time for the same time interval. The wind is not blowing through the tower, so the increase is not due to biasing from the tower and this trend is seen in each of the sensors along the height of the tower. In this case, the 15-minute averages track the trends quite well.

The next case appears to be very similar to the previous case. Figure 5 shows a comparison between 1-minute and 15-minute averages of the temperature structure parameter at 2 meters. The dashed line in this case is the temperature with time. As in Figure 3, the 15-minute averages track well with the 1-minute averages. In the previous case, the increase in the wind structure parameter appeared in each of the sensors; however, this does not hold true for this case. Figure 6 shows the comparison between 1-minute and 15 minute averages of the temperature structure parameter for the sensor located at 4 meters. In fact, the trend does not appear in any of the other sensors. This means that the 2 meter sensor was measuring a very localized phenomenon such as a person standing nearby or the heat from another instrument. Whatever the disturbance was, it persisted for an hour. This shows that one cannot just use the results from one sensor without examining the other sensors to determine whether or not the sensor being used is giving an adequate representation of the turbulence field.

Sometimes there is a more obvious source for the trend in the turbulence data. Figure 7 shows the comparison between the 1-minute and 15-minute averages of the temperature structure parameter at 2 meters. The trend is similar to the trend observed in Fig. 5. However, the source of this trend is the turbulent wakes of the tower. Figure 8 shows the wind speed and direction with time at the sensor. About 40 minutes into the measurement, the wind direction changes such that the tower is upwind from the sensor. When this occurs, the tower interferes with the normal turbulence field by modifying the

turbulence field. Therefore, the turbulence data cannot be used during the time the wind flow is coming through the tower.

The last case is a problem which occurs with any point measurement. Figure 9 shows the comparison between the 1-minute and 15-minute averages of the temperature structure parameter at 2 meters. This figure shows a large degree of variability between the 1-minute averages and the 15-minute averages. Looking at Fig. 10, the wind speed for most of the time is below 1 m/s. A wind speed this low causes problems in using the point measurements to represent the turbulence field. The turbulence field in this low of a wind speed becomes very localized. When the wind speed is this low, the turbulence measurement at one point will probably not correspond to a turbulence measurement at another point for the same height since the turbulence field is mainly influenced by the local obstacles.

## CONCLUSIONS

Sonic anemometers are very good for measuring wind speed, wind direction, temperature, heat flux, momentum flux, temperature structure parameter, and wind structure parameter at a fairly fast rate of 10 Hz. However, care must be used in examining the analyzed data from the sensors. Wind blowing through the tower before reaching the sensor will modify the turbulence field giving poor data for calculating the turbulence parameters. This can go for personnel or animals walking by the sensor. A low wind speed of less than 1 m/s causes the turbulence field to be strongly affected by the local terrain giving poor homogeneity to the turbulence field. Therefore, Taylor's frozen turbulence hypothesis can breakdown.

## ACKNOWLEDGEMENTS

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## REFERENCES

1. G.A. Daigle, J.E. Piercy, and T.F.W. Embleton, "Effects of Atmospheric Turbulence on the Interface of Sound Waves Near a Hard Boundary," *J. Acoust. Soc. Am.* **64**, 622-630 (1978).
2. V.I. Tatarski, *The Effects of Turbulent Atmosphere on Wave Propagation*, translated and published by Israel Programs for Scientific Translations Ltd., Jerusalem, (1971).

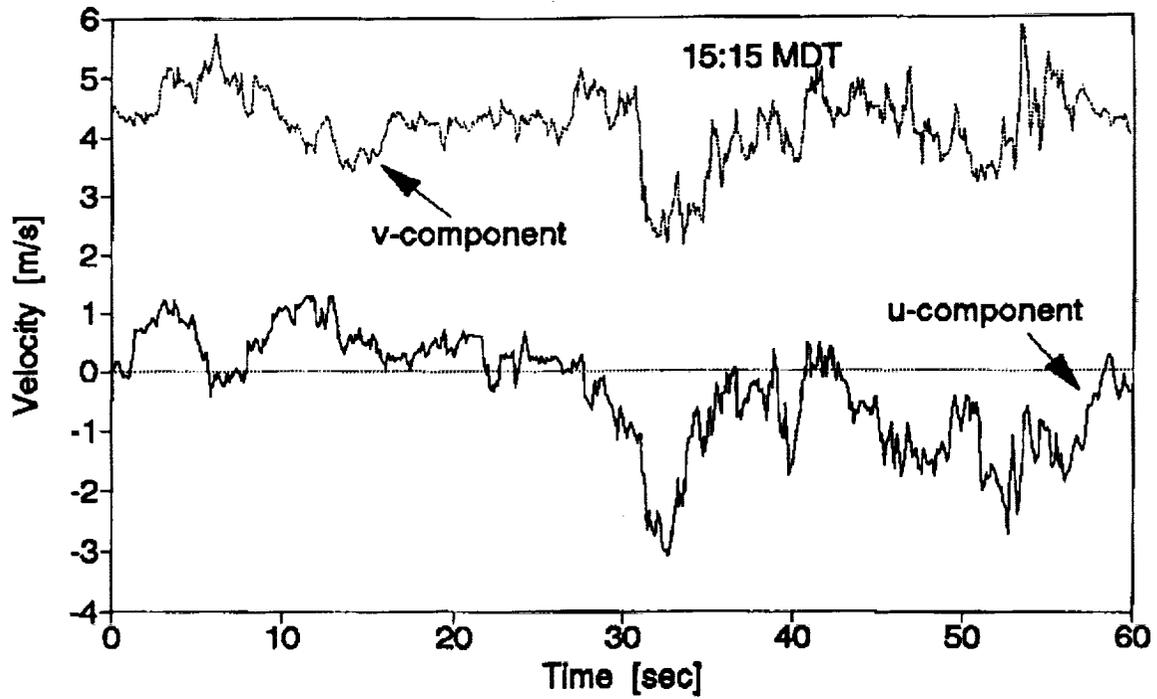


Figure 1. Sonic u and v wind components at 16 meters from August 28, 1991 at DIRT Site located at White Sands Missile Range, New Mexico.

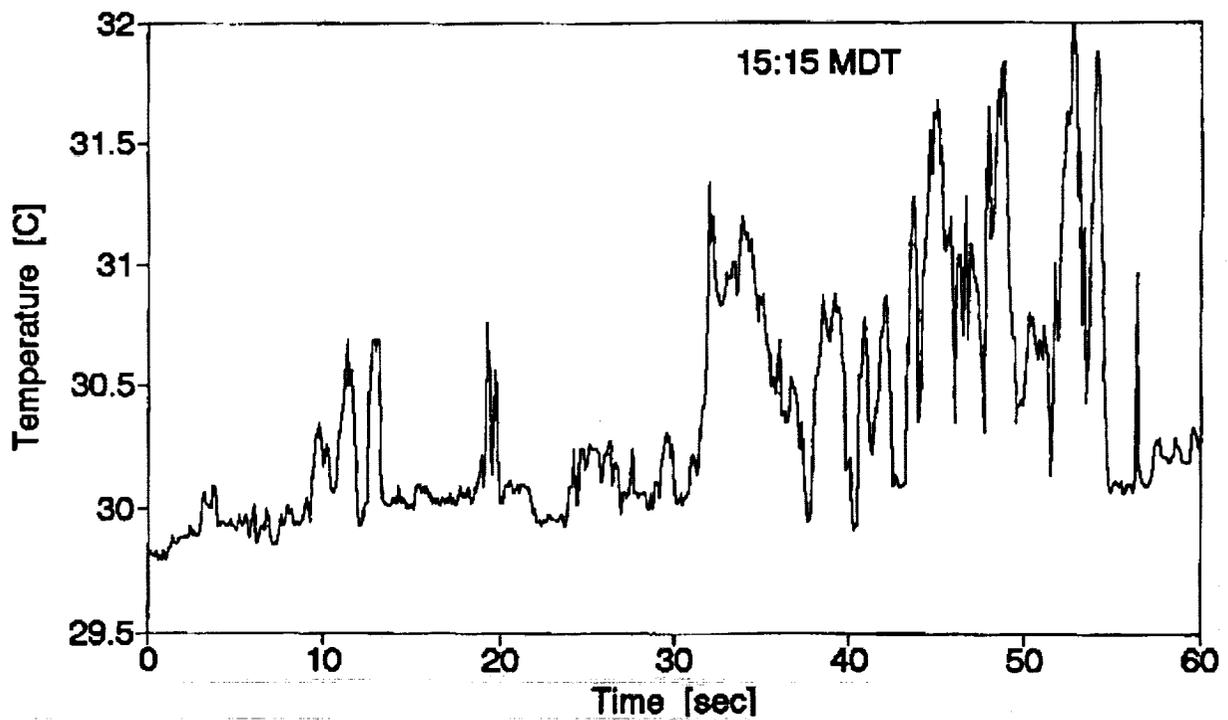


Figure 2. Sonic temperature at 16 meters from August 28, 1991 at DIRT Site located at White Sands Missile Range, New Mexico.

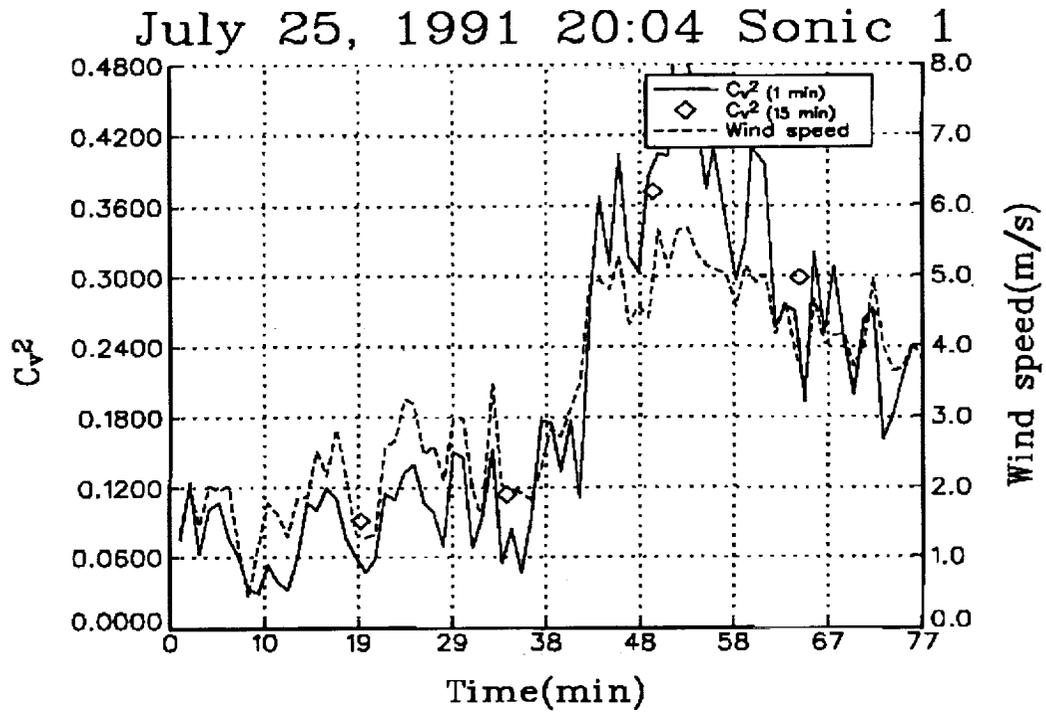


Figure 3. Plot of the 1-minute and 15-minute wind structure parameters along with 1-minute averaged wind speed with time at 2 meters.

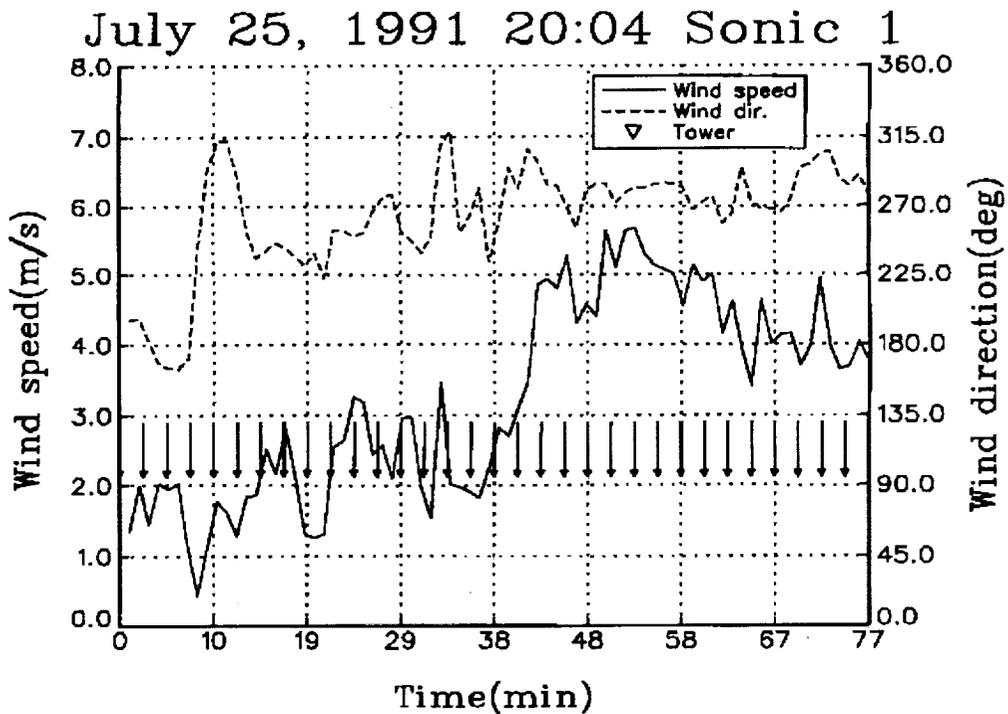
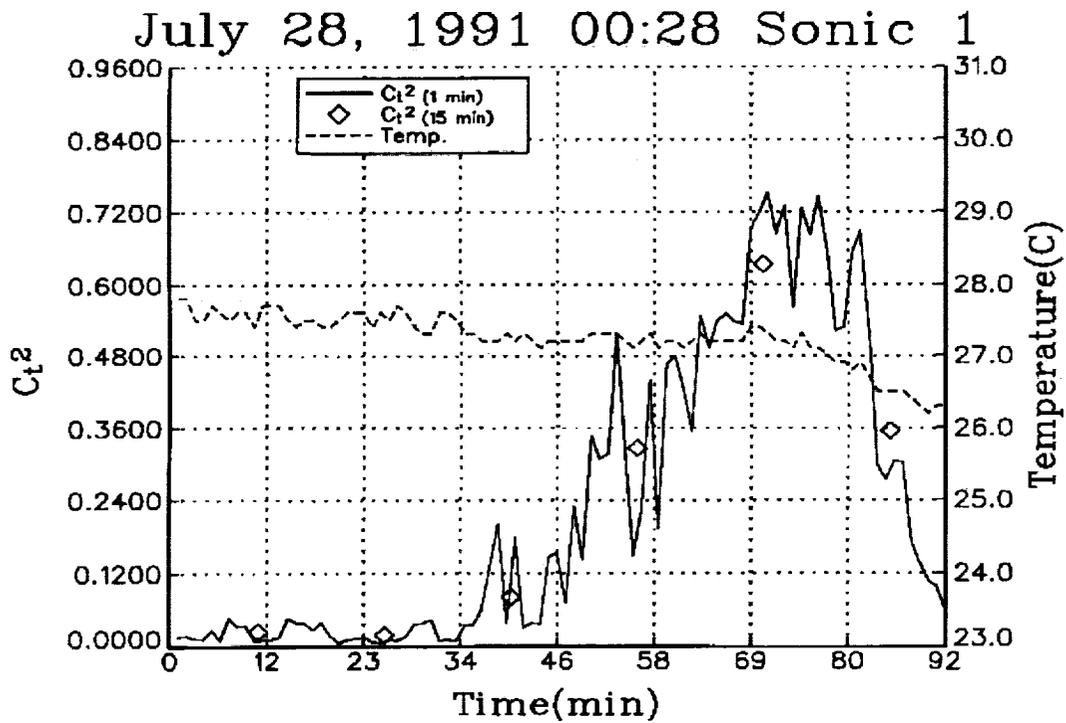
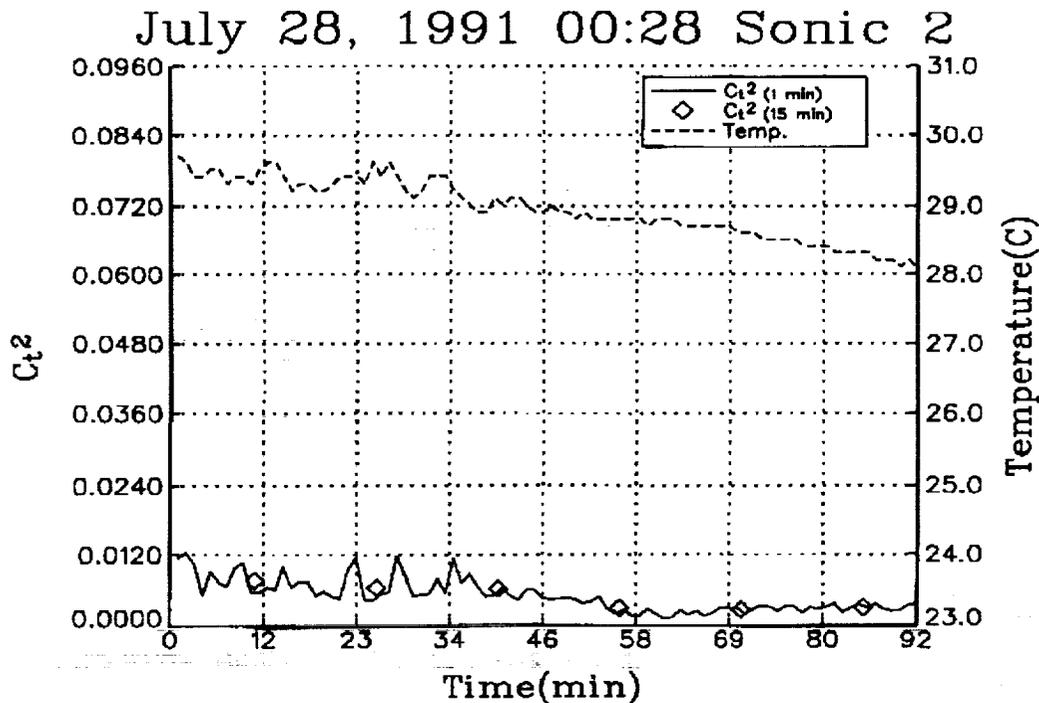


Figure 4. One-minute averaged wind speed and direction with time at 2 meters. Arrows indicate direction of tower from sonic anemometer.



**Figure 5.** Plot of 1-minute and 15-minute averages of the temperature structure parameter and 1-minute averaged temperature with time at 2 meters.



**Figure 6.** Plot of 1-minute and 15-minute averages of the temperature structure parameter and 1-minute averaged temperature with time at 4 meters.

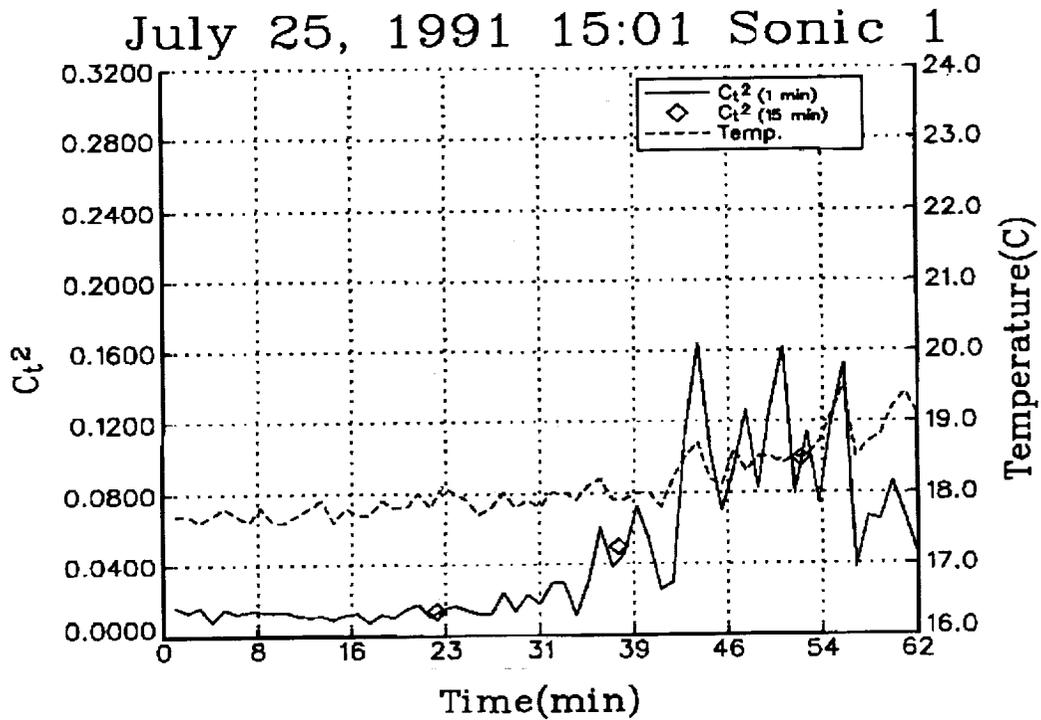


Figure 7. Plot of 1-minute and 15-minute averages of the temperature structure parameter and 1-minute averaged temperature with time at 2 meters.

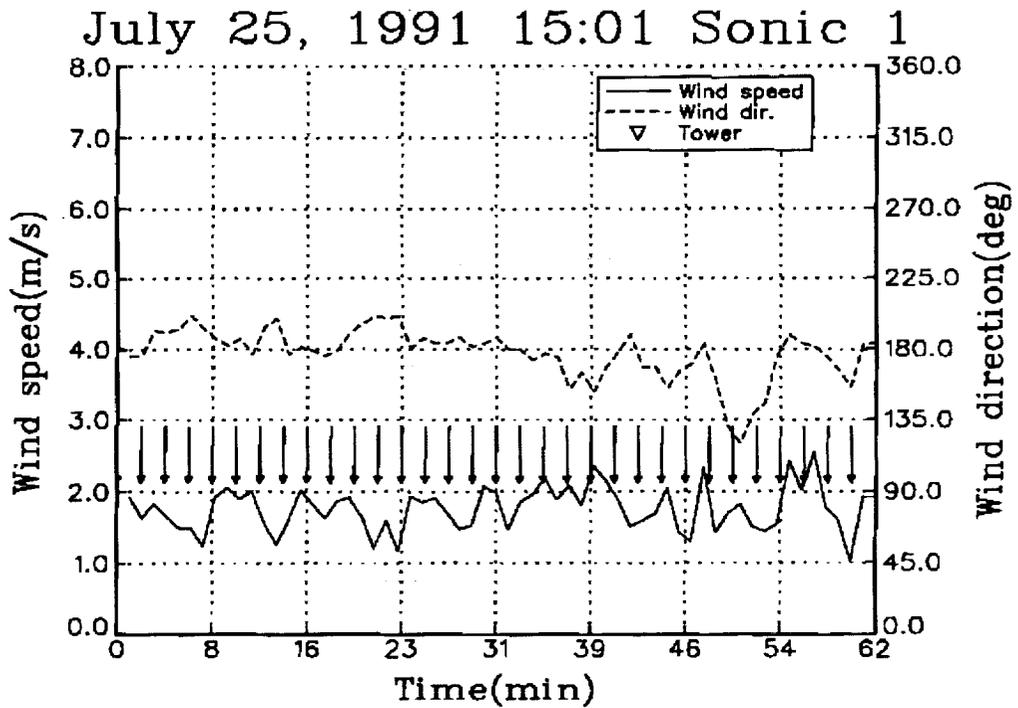


Figure 8. Plot of 1-minute averaged wind speed and direction with time at 2 meters. The arrows indicate the direction of the tower from the sonic anemometer.

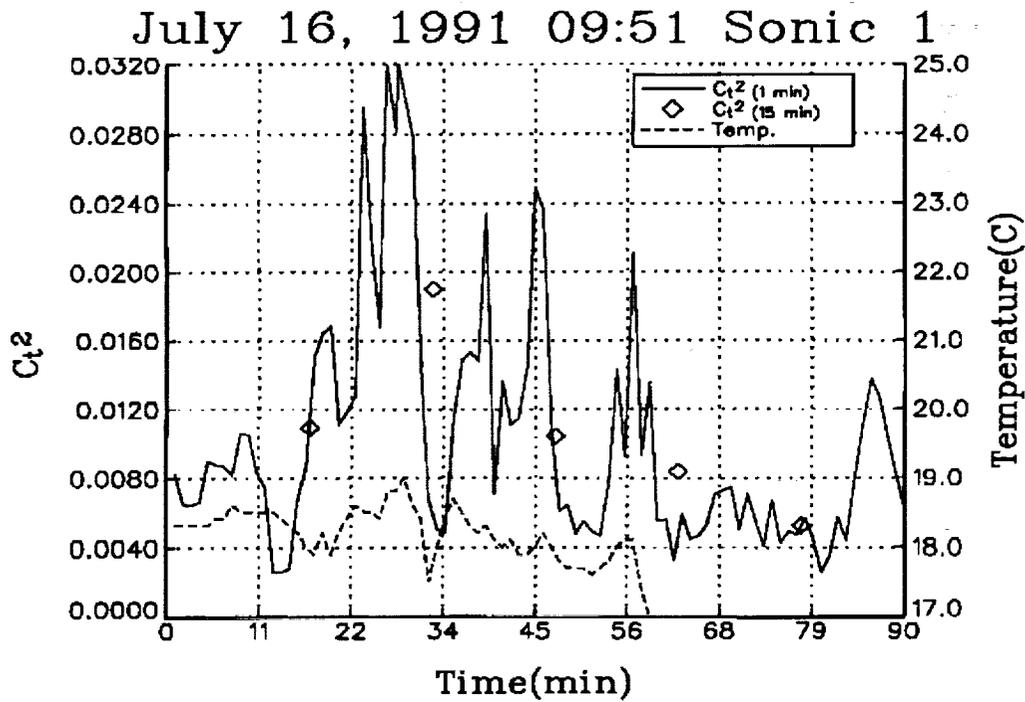


Figure 9. Plot of 1-minute and 15-minute averages of the temperature structure parameter and 1-minute averaged temperature with time at 2 meters.

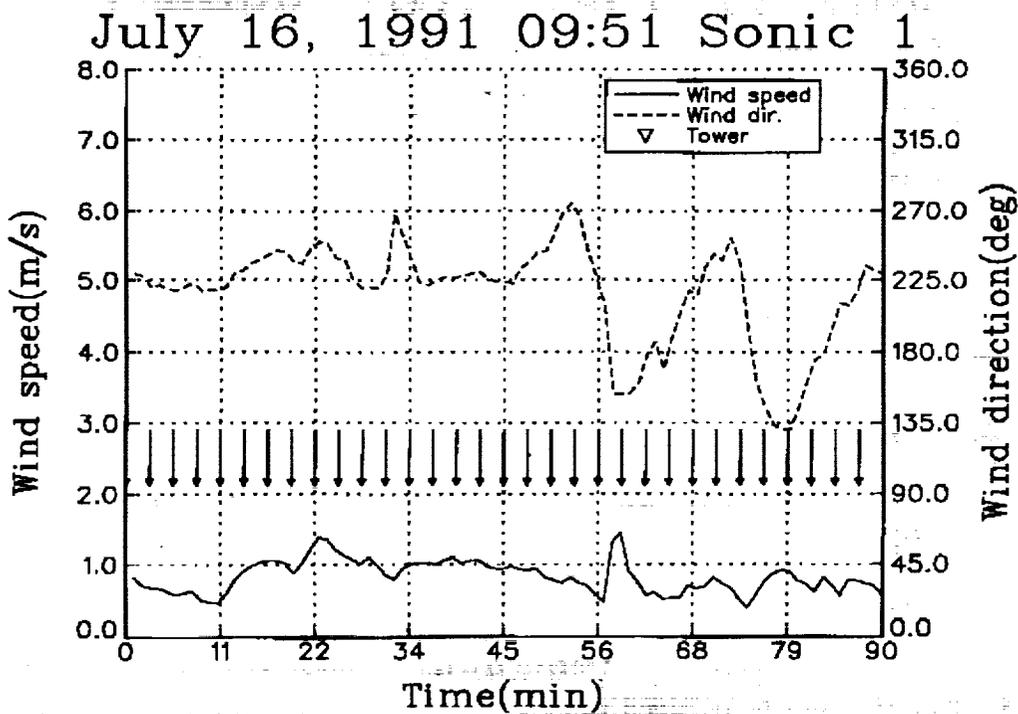


Figure 10. Plot of 1-minute averaged wind speed and direction with time at 2 meters. The arrows indicate the direction of the tower from the sonic anemometer.